BIOMORPHIC EXPLORERS LEADING TOWARDS A ROBOTIC ECOLOGY

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DARPA/ISAT STUDY MEETING: TOWARDS A ROBOTIC ECOLOGY
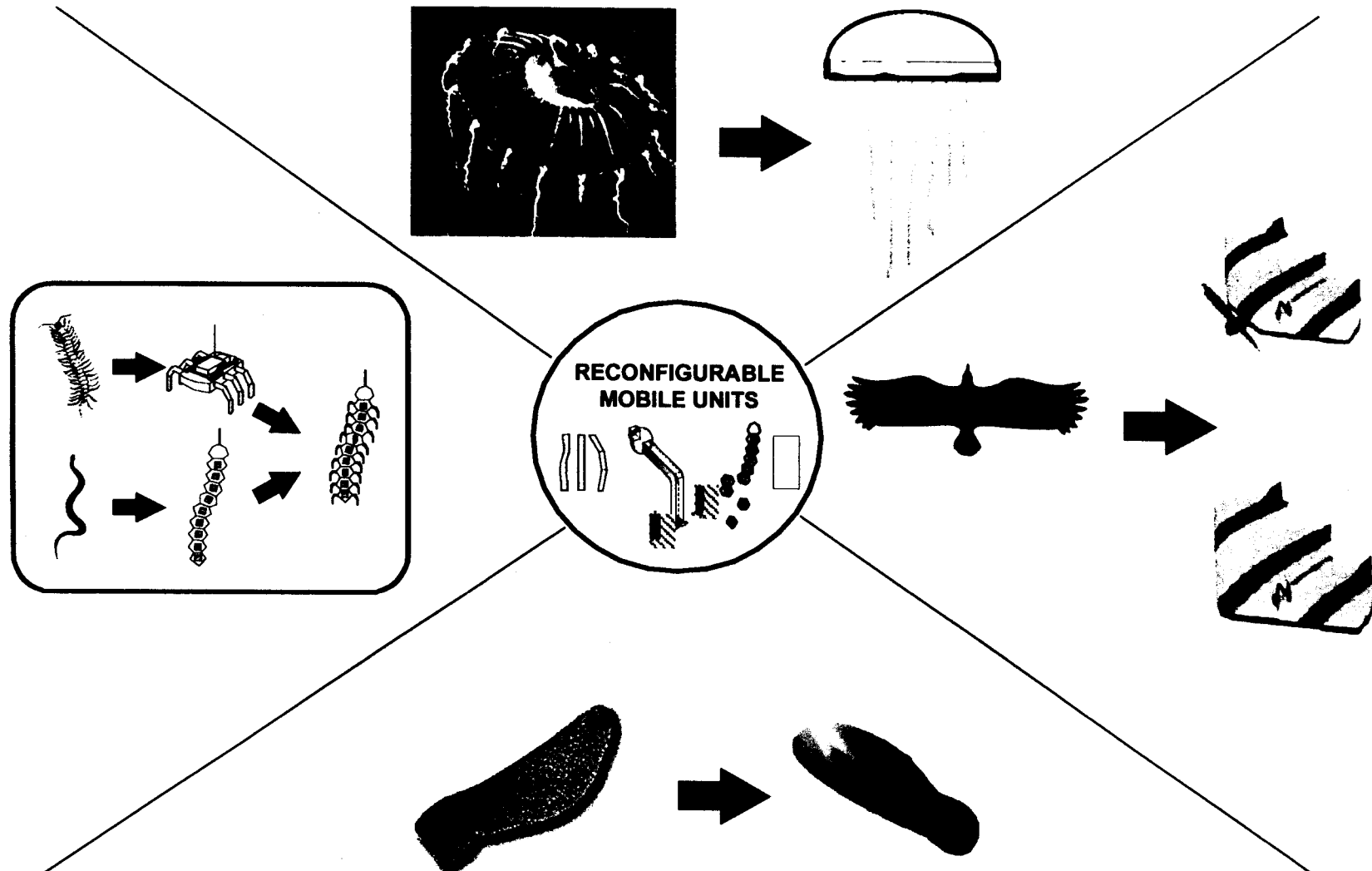~~March 9-10~~, 1999, ~~Jet Propulsion Laboratory~~

April 26, 27.   M I T.

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BIOMORPHIC EXPLORERS

- **COOPERATIVE BEHAVIORS OF VERSATILE MOBILE ENTITIES**   *versatile mobility*

  - **INTERDEPENDENCE**   *distributed operation*

  - **EFFICIENT USE OF NATURAL AND EXISTING RESOURCES**

- **TO PROVIDE EXTENDED SURVIVAL AND USEFUL LIFE OF THE ROBOTS TOWARDS FULFILLMENT OF THE MISSION/APPLICATION**
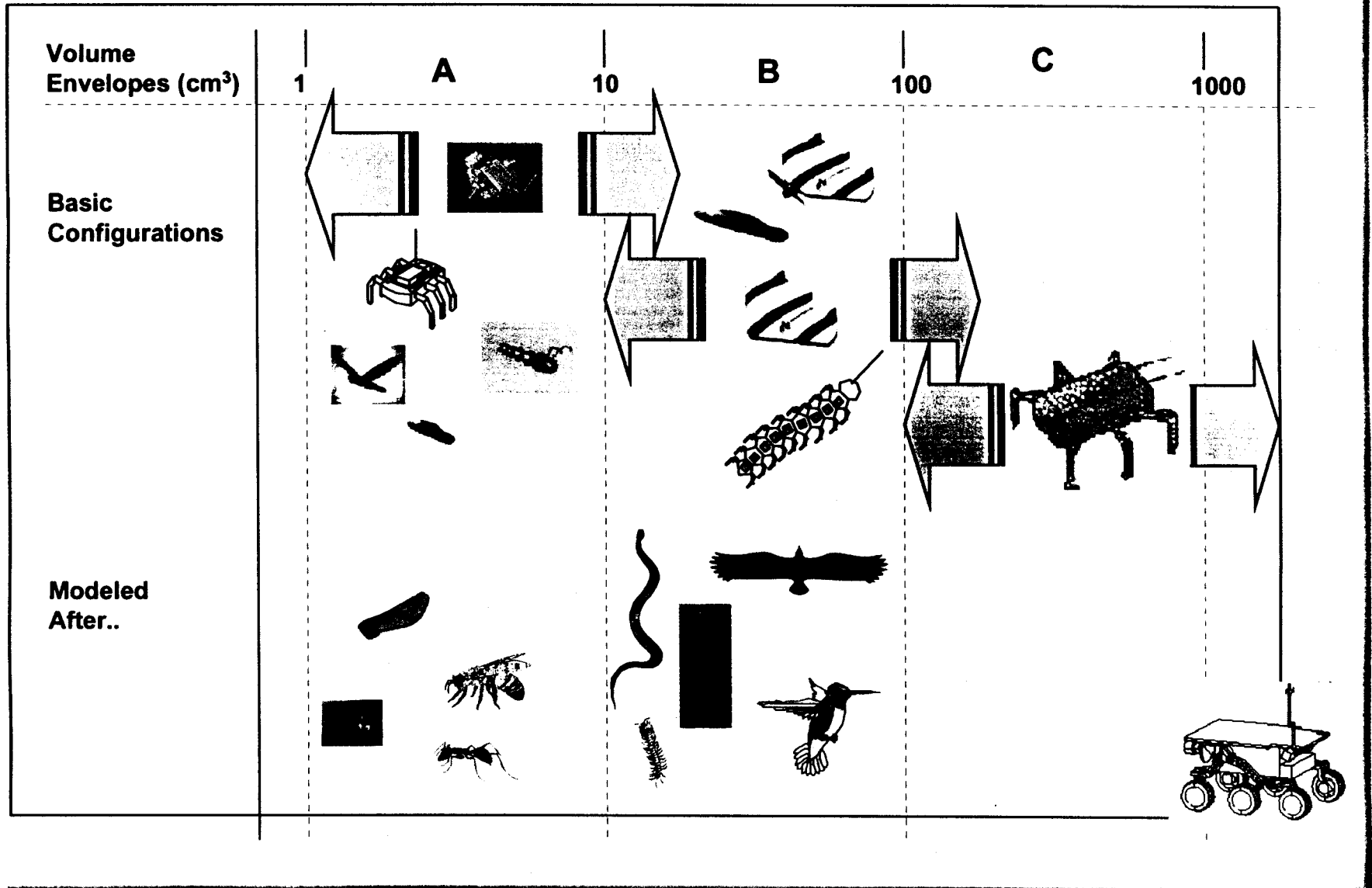
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BIOMORPHIC EXPLORERS

- **SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL EXPLORERS**

    - **VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids**

    - **ADAPTIVE, DISTRIBUTED OPERATION**

    - **BIOMORPHIC COOPERATIVE BEHAVIOR**

- **CONDUCTED WORKSHOP, AUG 19-20, 1998**

    - **SPONSORED BY NASA/JPL**

    - **VERY SUCCESSFUL; OVER 150 PARTICIPANTS**

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ADVANCED MOBILITY FOR BIOMORPHIC EXPLORERS

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BIOMORPHIC EXPLORERS: SIZE BASED CLASSIFICATION

Volume Envelopes (cm³)

	1	A	10	B	100	C	1000

Basic Configurations

Modeled After..

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Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)
Biomorphic Explorers

Aerial

Surface/Subsurface

| Biomorphic Surface Systems | Biomorphic Subsurface Systems |

Seed Wing

Honey Bee

Ant

Soaring Bird

Humming Bird

Snake

Centipede

Jelly Fish

Earthworm

Germinating Seed
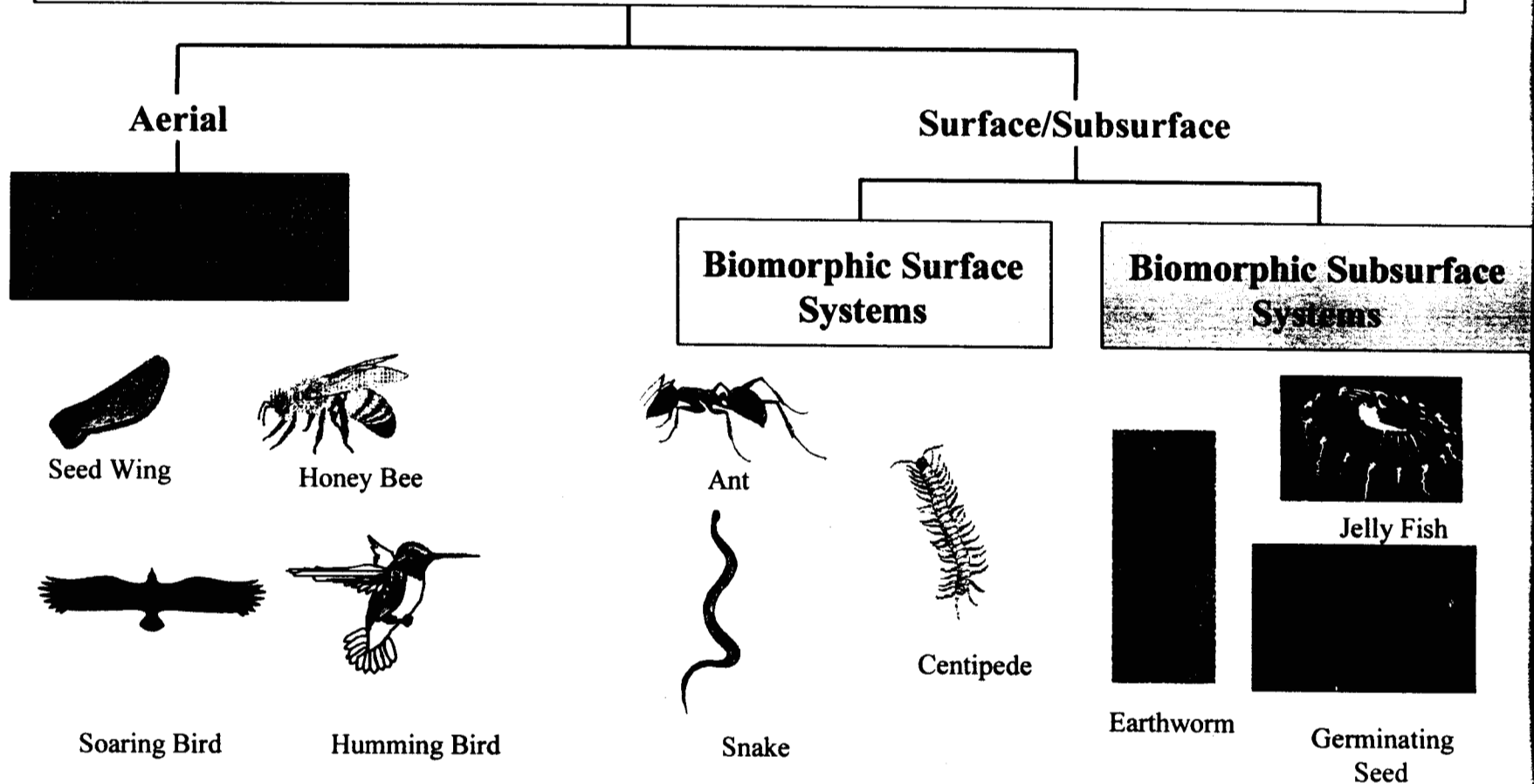
**Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class**

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Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)
Biomorphic Explorers

Aerial

Surface/Subsurface

Biomorphic Surface Systems

Biomorphic Subsurface Systems

Seed Wing Flyer (60 g)

Ornithopter

Glider (75 g)

Powered Flyer

Hexapod (1-2 kg)

Reconfigurable Legs/Feet

Artificial Earthworm

Artificial Jelly Fish

Worm Robot (85 g)
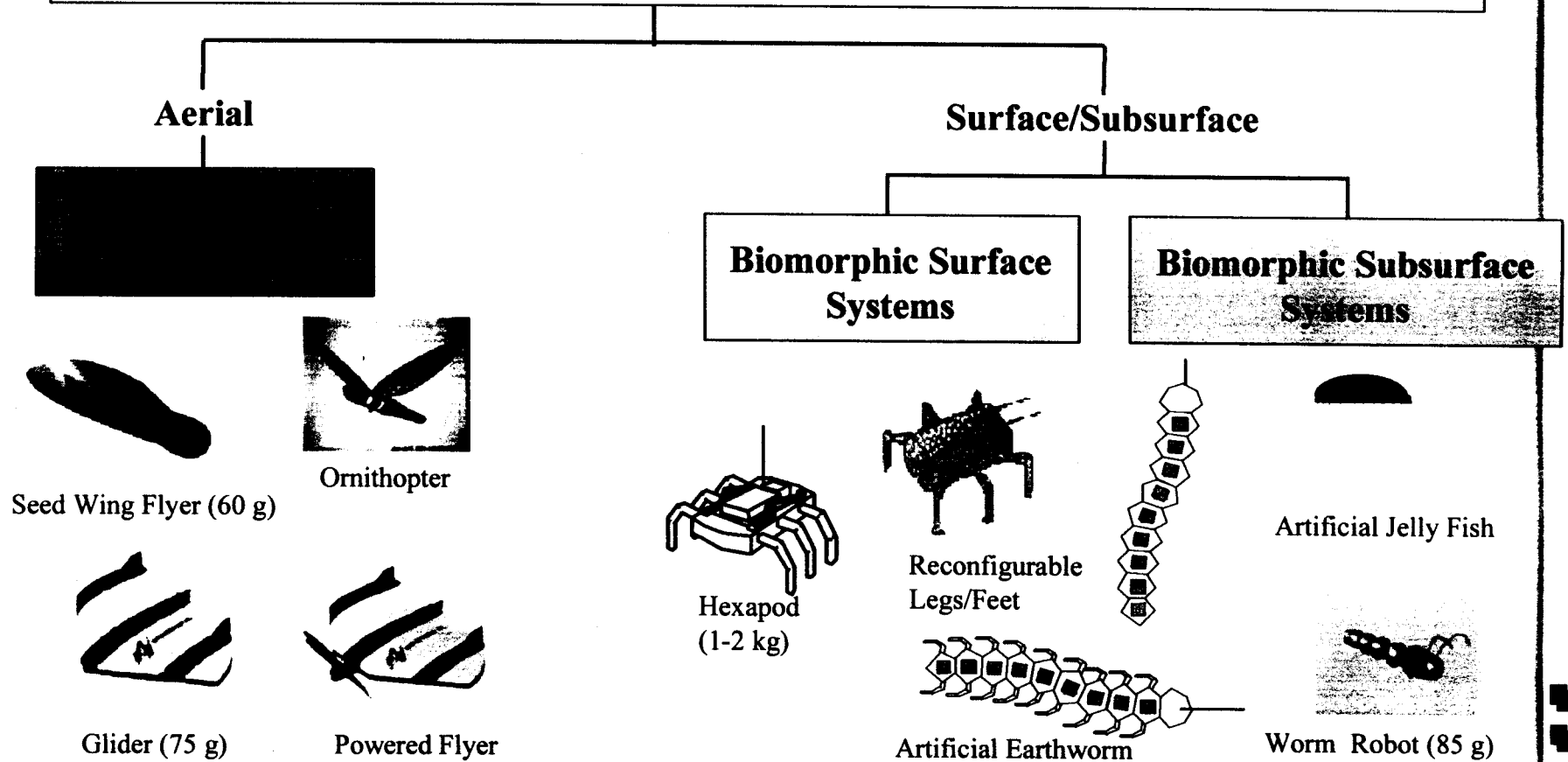
Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses

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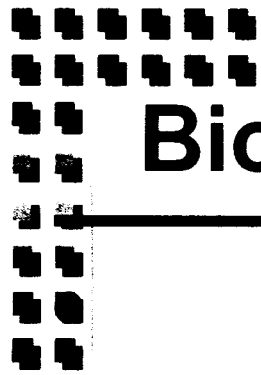
Biomorphic Flight Systems: Vision

- **Extended reach over all kinds of terrain**

- **Unique perspective for imaging and Spectral Signature**

- **Many flyers work in cooperation with larger aircraft, and balloons to enable new missions to reach currently inaccessible locations**

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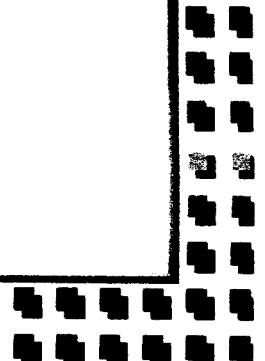
BIOMORPHIC FLIGHT SYSTEMS

a. Seed Wing Pod

b. Seed Wing Pod Flyer

TOTAL MASS: 57 g →
PAYLOAD MASS: 48 g

TOTAL MASS: 57 g ←
PAYLOAD MASS: 32 g

TOTAL MASS: 57 g →
PAYLOAD MASS: 6 g

c. Biomorphic Glider

d. Biomorphic Flyer

Biomorphic flight systems offer rapid mobility and extended reach. For comparison the above illustrates for the same total mass of the system, the respective payload fractions in each case

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COORDINATED/COOPERATIVE EXPLORATION SCENARIO

BIOMORPHIC FLYERS

•ATMOSPHERIC INFO GATHERING:
•DISTRIBUTED MULTIPLE SITE MEASUREMENTS
•CLOSE-UP IMAGING, EXOBIOLOGY SITE SELECTION
•DEPLOY PAYLOAD: INSTRUMENTS/CRAWLERS
•SAMPLE RETURN RECONNAISSANCE

LANDER/ ROVER

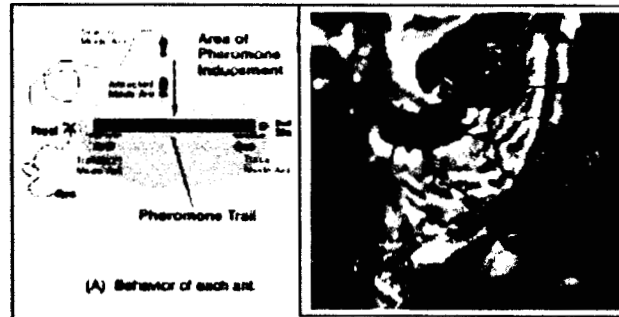INFO DOWNLINK TO LOCAL RELAY

JAVELIN

COM PORT 2

SURFACE

BIOMORPHIC CRAWLERS WORM ROBOT

INACCESSIBLE AREA

COM PORT 1

COOPERATIVE ORGANIZATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.

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10

Insects operating cooperatively :

**Nakamura and Kurumatani, 1995
Kubo, 1996**

Ants' elaborate communication method with pheromone trails
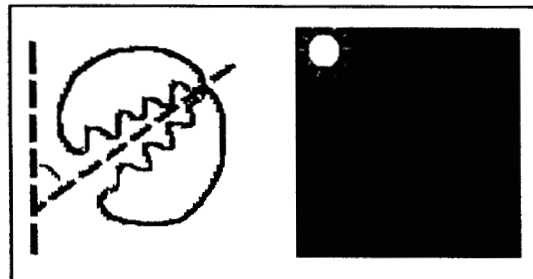
**Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997**

Honeybee's recruitment dance with the sun as a celestial reference

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BIOMORPHIC EXPLORERS

- **PAYOFF**

- **BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE**

    - **EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS**

    - **MUCH BROADER COVERAGE OF EXPLORATION SITES**

    - **EXPLORATION AT LOWER COST**

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Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay

Probe enters
atmosphere

Parachute deployed

Heat shield released and antenna
deployed (14 km).

Larger Aircraft (Large Glider)
released (13 km)

Large Glider flies
preset flight plan
deploying the
biomorphic gliders

Local relay
collects and
transmits data
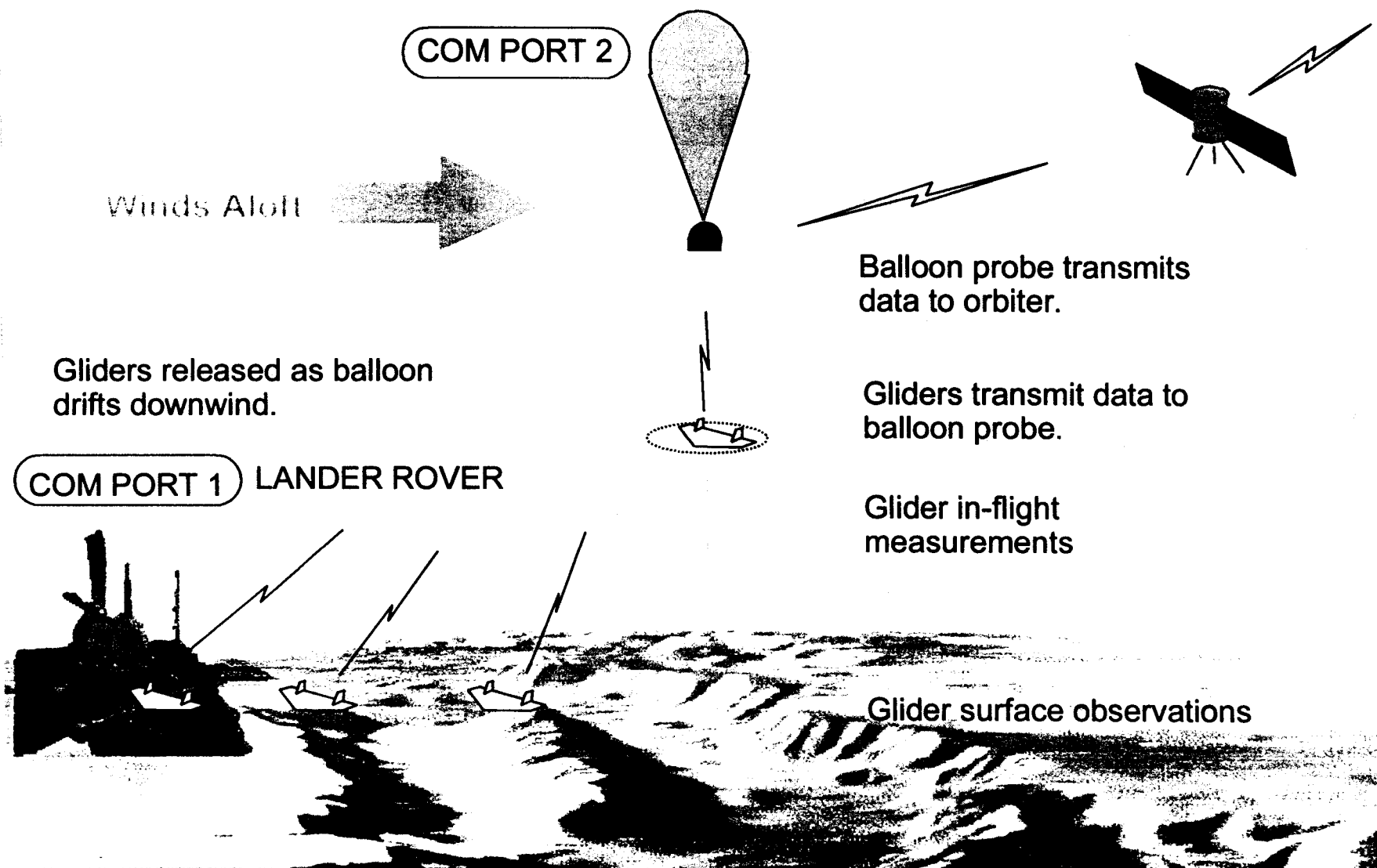to orbiter

Gliders
transmit data
to local relay.

LARGER GLIDER

COM PORT 1

COM PORT 2

JAVELIN

LANDER ROVER

Surface measurements

morphic Gliders perform in-flight
ements (12 km to surface)

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Biomorphic Glider Deployment Concept: Balloon Deploy/Dual Relay

COM PORT 2

Winds Aloft

Balloon probe transmits
data to orbiter.

Gliders released as balloon
drifts downwind.

Gliders transmit data to
balloon probe.

COM PORT 1) LANDER ROVER

Glider in-flight
measurements

Glider surface observations

14

Biomorphic Explorer: Conceptual Design

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL
ALGORITHMS

μSENSORS

GLIDER SELECTED

RECONFIGURABILITY

μCOMMUNICATION

TEMPERATURE
CONTROL

μSTRUCTURE

ADVANCED
MOBILITY

μCOMPUTING

μPOWER

μNAVIGATION
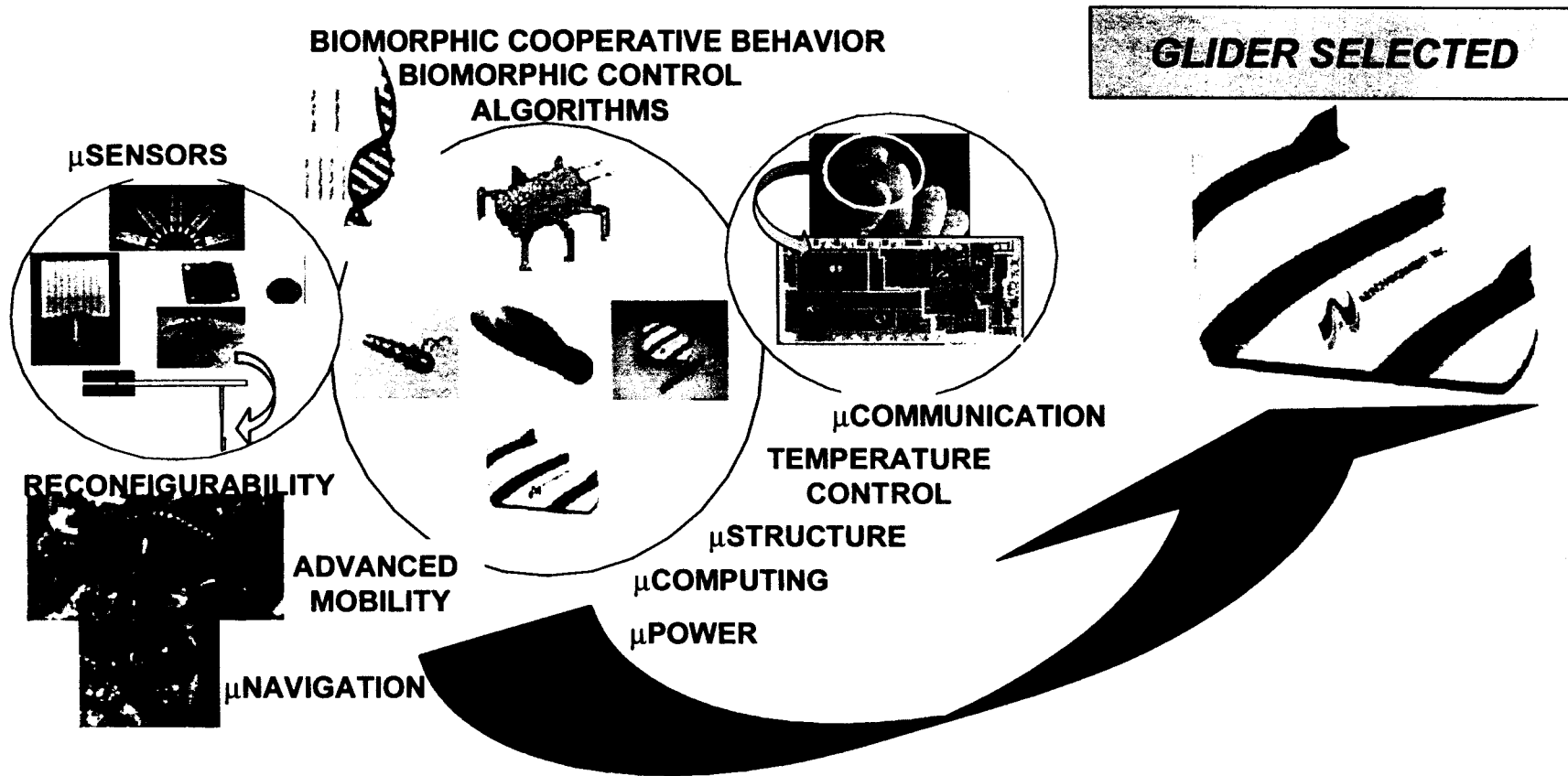
SELECTION CRITERIA

- *LOW MASS/VOLUME*
- *HIGH PAYLOAD FRACTION*
- *LARGE RANGE OF MOBILITY*
- *ACTIVE CONTROL*
- *IMPLEMENTATION READINESS*

GLIDER BASELINE DESIGN CHARACTERISTICS

- *MASS: 75 g*
- *PAYLOAD FRACTION : 60 %*
- *GLIDE RATIO, L/D ~ 5.8*
- *LARGE RANGE OF AERIAL MOBILITY:*
  ~ 50 km to 100 km
- *LEVERAGE FROM MAV TECHNOLOGY*

- *VOLUME: 300 cm³*
- *ACTIVE FLIGHT CONTROL*
- *SOLAR NAVIGATION*
- *SOARING FLIGHT IN RISING CURRENTS*
- *COOPERATIVE MISSION: 32 GLIDERS*
- *COVERAGE AREA: ~ 100 km x 100 km*

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Biomorphic Gliders

- **Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.**

- **Payload mass fraction 50% or higher.**

- **small mass (100 g - 500 g)**
- **low radar cross section**
- **larger numbers for given payload due to low mass**
- **amenable to cooperative behaviors**
- **missions use potential energy: deploy from existing craft at high altitude**
- **Captures features of soaring birds, utilizing rising currents in the environment**
- ***Adaptive Behavior***
- ***Self Repair features***

SOARING IN BIRDS
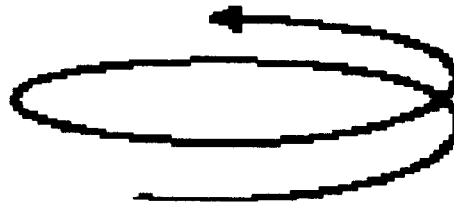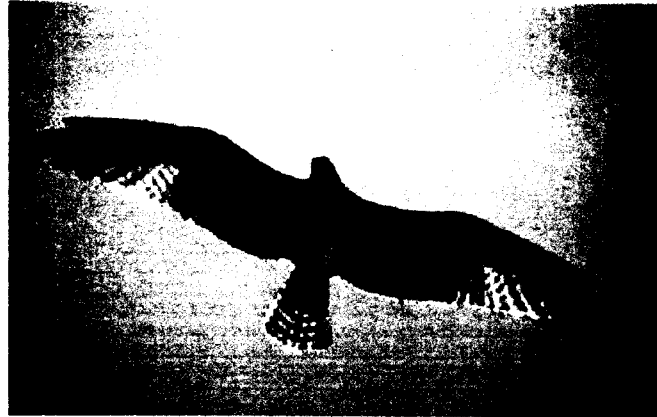
Vulture

For vultures and many other large birds, flying involves little effort. They hold their wings out and rise high into the sky by soaring — circling upward on columns of rising warm air called thermals. At the top of one thermal, they glide gently down in search of the next.

* Bird Photo by R.W. Scott and G. J. Scott

# Biomorphic Glider Deployment/Telecommunication Concept

Probe enters atmosphere

Parachute deployed

Relay to Earth

Heat shield and gliders released (12-14 km).

In flight measurements (12 km to surface)

Gliders transmit data to local relay using self-organized, self-routing network, which changes dynamically during the flight and after landing, to communicate optimally the information to the local relay

LANDER ROVER

COM PORT 1

JAVELIN

COM PORT 2

Surface measurements

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18
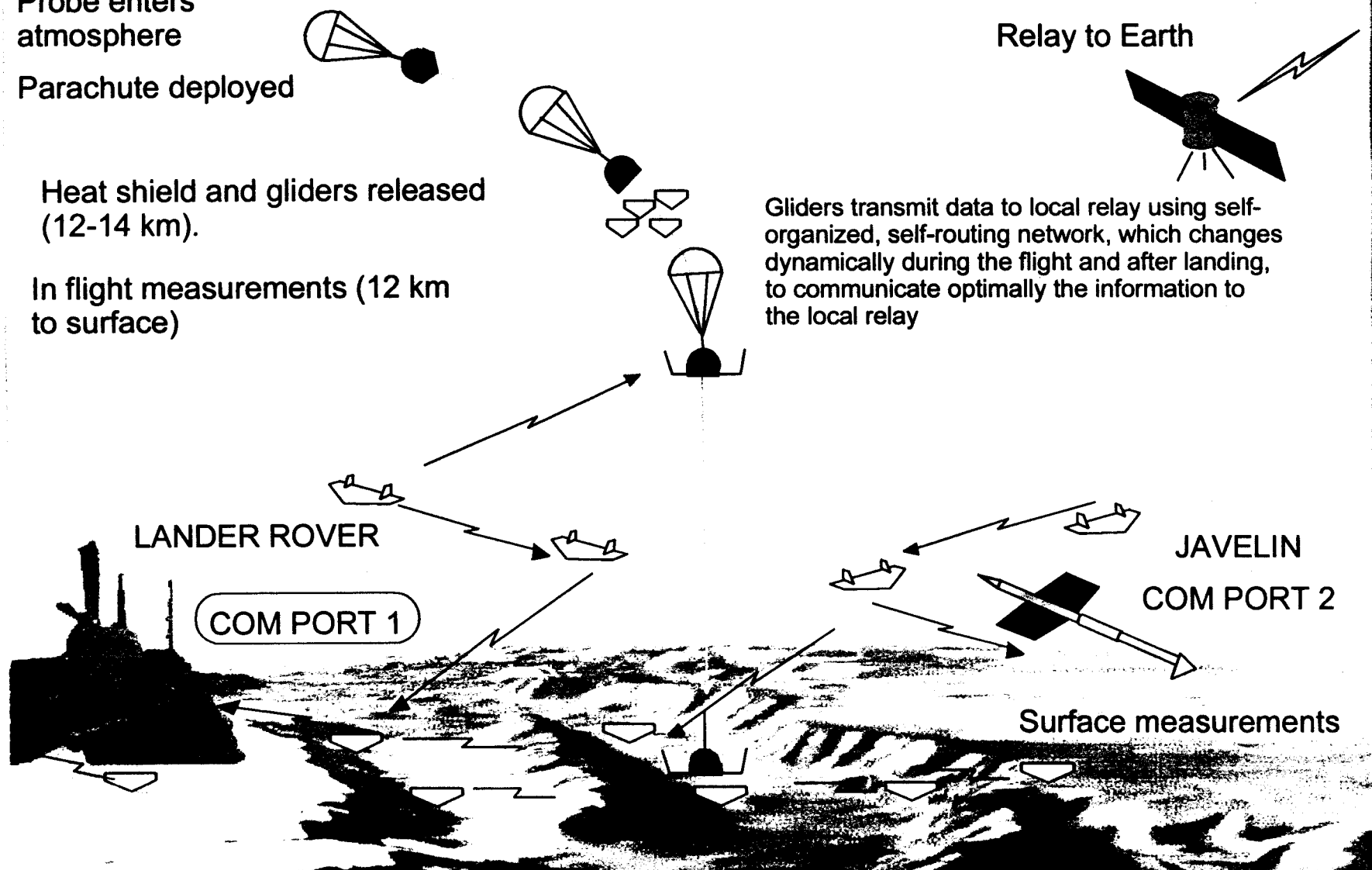
Applications

- **Distributed Aerial Measurements**
  - **Ephemeral Phenomena**
  - **Extended Duration using Soaring**

- **Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents**

- **Close-up Imaging, Site Selection**

  - **Meteorological Events: storm watch**
  - **Reconnaissance**
  - **Biological Chemical Warfare**
  - **Search and Rescue etc**
  - **Surveillance**
  - **Jamming**

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Demonstrated optical correlator can be miniaturized to fit in a small interceptor

OPTICAL CORRELATOR SCHEMATIC
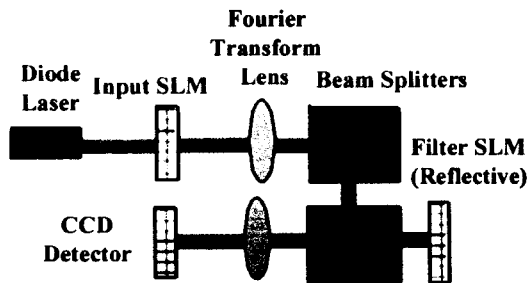
BMDO FUNDED CAMCORDER-SIZED GRAYSCALE OPTICAL CORRELATOR JPL - 1998

MATCH-BOX SIZED OPTICAL CORRELATOR TO BE DELIVERED FOR DOD AND NASA APPLICATIONS

Diode Laser

Input SLM

Fourier Transform Lens

Beam Splitters

Filter SLM (Reflective)

CCD Detector

Optical correlator provide wide-area search and track at the speed of light independent of sensor resolutions
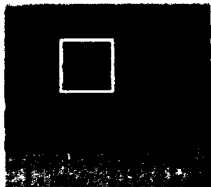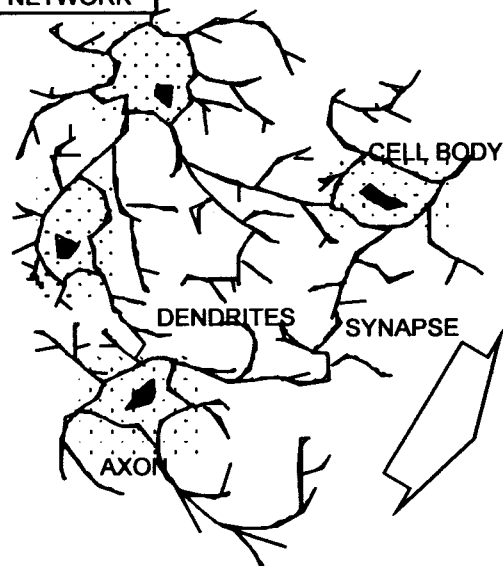
Input scene

Correlator output

JPL'S OPTICALCORRELATOR SETUP INSIDE THE VIGILANTE INSTRUMENT TRAILER DURING TEST AT MOJAVE (NOV. 1998)

VIGILANTE sensor platform and trailer

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Background for 3-Dimensional Artificial Neural Network (3DANN)

BIOLOGICAL NEURAL NETWORK

CELL BODY

DENDRITES SYNAPSE

AXON

ARTIFICIAL NETWORK MODEL

INPUTS

INTER CONNECTION WEIGHTS

PROCESSING ELEMENT

OUTPUTS

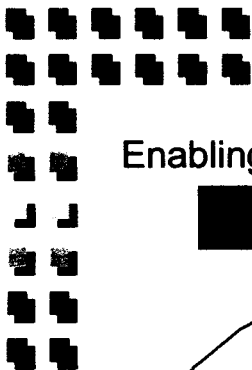*LtGen. Lyles*

10 gm, 5 cc, 2 W
On-chip IR detector
1 trillion 8-bit multiplies/sec
270 million template matches/sec
Compute power greater than fast
 supercomputer

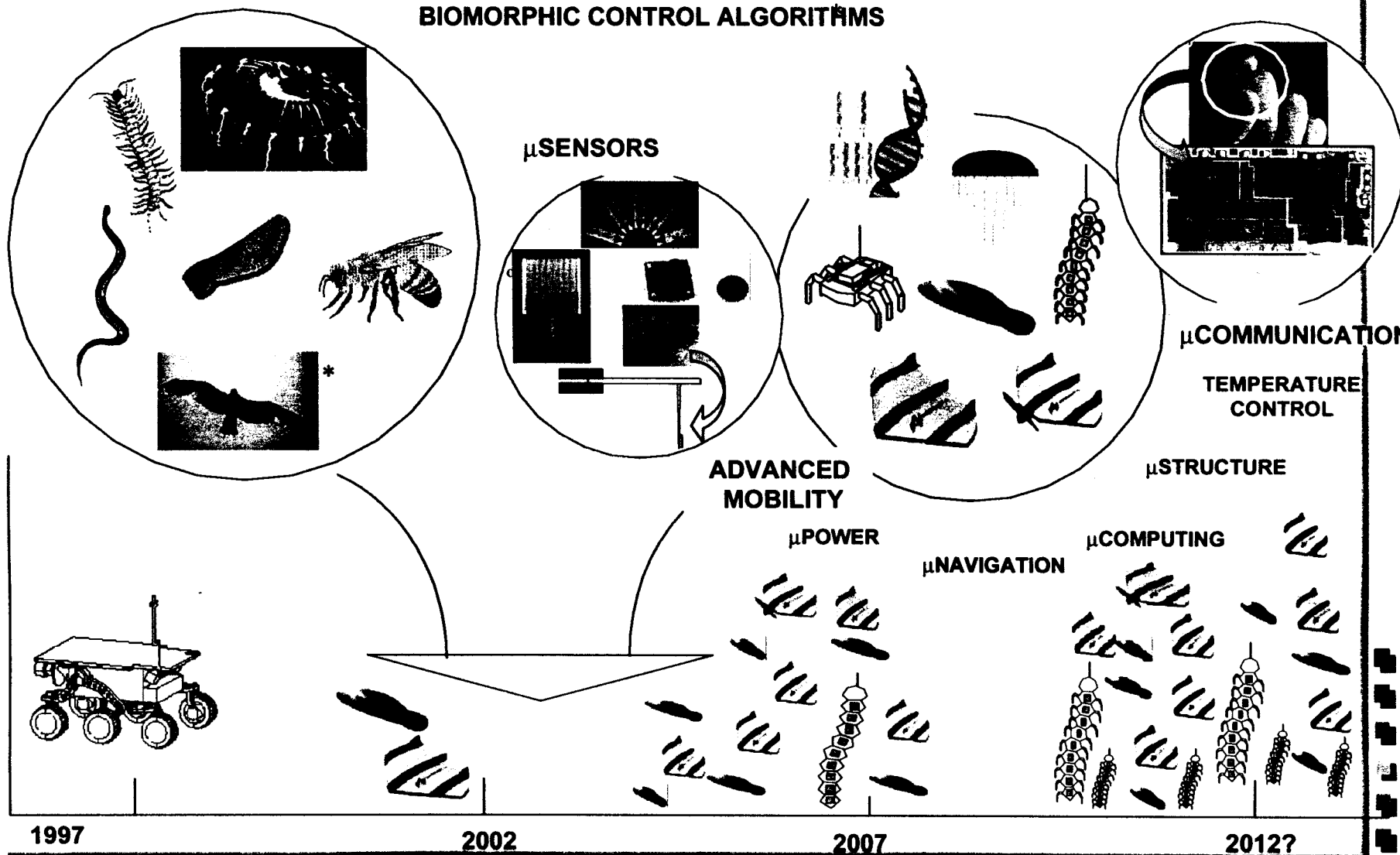*JPL neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for ATR.*
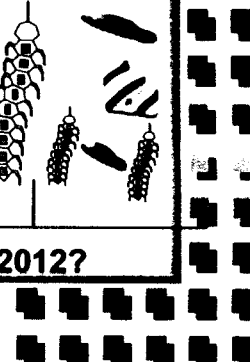
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SUMMARY & ROADMAP

Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

BIOMORPHIC COOPERATIVE BEHAVIOR
BIOMORPHIC CONTROL ALGORITHMS

μSENSORS

μCOMMUNICATION

TEMPERATURE
CONTROL

μSTRUCTURE

ADVANCED
MOBILITY

μPOWER

μNAVIGATION

μCOMPUTING

| 1997 | 2002 | 2007 | 2012? |

* Bird Photo by R.W. Scott and G. J. Scott

22

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ACKNOWLEDGMENTS

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